5. Other Gases: Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride

Overview

Total U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990-2005

Estimated 2005 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	160.2
Change Compared to 2004 (Million Metric Tons Carbon Dioxide Equivalent)	10.7
Change from 2004 *(Percent)*	*7.2%*
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	73.2
Change from 1990 *(Percent)*	*84.0%*

U.S. emissions of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) in 2005, according to the U.S. Environmental Protection Agency (EPA), totaled 160.2 million metric tons carbon dioxide equivalent ($MMTCO_2e$). Collectively, these "other gases" represented 2.2 percent of total U.S. greenhouse gas emissions. Their 2005 emissions were 7.2 percent (10.7 $MMTCO_2e$) above the 2004 level of 149.5 $MMTCO_2e$, an increase attributed primarily to an 8.9-percent (10.7 $MMTCO_2e$) increase in emissions of HFCs.

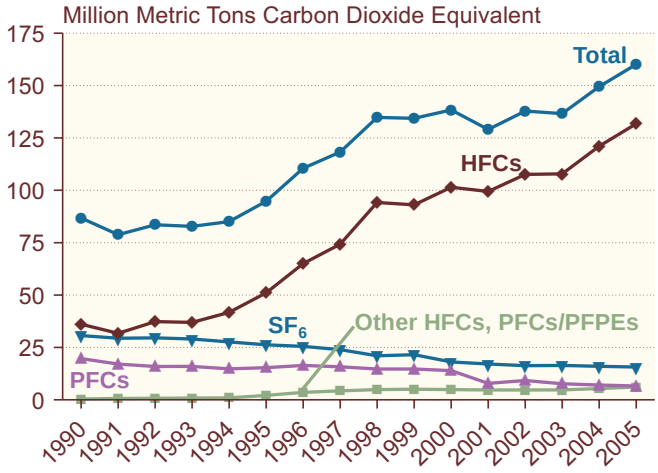
Table 31 at the end of this chapter shows U.S. emissions of HFCs, PFCs, and SF_6 from 1990 to 2005 in carbon dioxide equivalent units, and Table 32 shows their emissions in metric tons of native gas. U.S. emissions of HFCs, PFCs, and SF_6 were 84 percent (73.2 $MMTCO_2e$) higher in 2005 than in 1990 (87.1 $MMTCO_2e$). Revised EPA data for 1990-2004 and new estimates for 2005 show that annual emissions of HFCs have increased significantly since 1990; emissions of PFCs have declined by two-thirds; and SF_6 emissions have declined by almost one-half since 1990 (Figure 4).

The increase in HFC emissions since the early 1990s reflects the use of HFCs as replacements for CFCs (chlorofluorocarbons), HCFCs (hydrochlorofluorocarbons), halons, and other ozone-depleting substances (ODS) that are being phased out under the Montreal Protocol because they damage the Earth's stratospheric ozone layer. ODS are used in a variety of applications, including refrigeration and air conditioning, solvents, foam production, fire extinguishers, aerosols, and sterilization.

PFC emissions have trended downward since 1990, largely as a result of reduced PFC emissions from the aluminum industry, both because of industry efforts to reduce emissions and because aluminum production has declined. SF_6 emissions have also fallen since 1990, mainly due to reduced emissions from electricity transmission and distribution in the electric power industry and increased prices for SF_6.

The emissions estimates in Table 31 are based on data provided by the EPA's Office of Air and Radiation.[75] The EPA data, provided in units of native gas (thousand metric tons), were converted to carbon dioxide equivalent units by the Energy Information Administration (EIA), using values for the global warming potential (GWP) for each gas from the 2001 Third Assessment

Figure 4. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990-2005



Source: Estimates presented in this chapter.

[75]Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.

Report of the Intergovernmental Panel on Climate Change (IPCC). The estimates in Table 32 are taken directly from data supplied by the EPA's Office of Air and Radiation. The 2005 preliminary estimates developed by the EPA and provided to EIA include some revisions to historical emissions estimates, based on recent runs of the EPA's Vintaging Model (see boxes on pages 63 and 64). Those revisions are reflected in the emissions estimates presented in this chapter.

Hydrofluorocarbons (HFCs)

U.S. Emissions of Hydrofluorocarbons, 1990-2005

Estimated 2005 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	131.8
Change Compared to 2004 (Million Metric Tons Carbon Dioxide Equivalent)	10.7
Change from 2004 *(Percent)*	*8.9%*
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	95.7
Change from 1990 *(Percent)*	*265.4%*

The EPA estimates U.S. emissions of HFCs in 2005 at 131.8 $MMTCO_2e$, equivalent to 1.7 percent of total U.S. greenhouse gas emissions.[76] HFC emissions in 2005 were 8.9 percent (10.7 $MMTCO_2e$) above the 2004 level of 121.1 $MMTCO_2e$ (Table 31). The overall increase included increases in emissions of HFC-23 (0.9 $MMTCO_2e$), HFC-32 (0.1 $MMTCO_2e$), HFC-125 (2.3 $MMTCO_2e$), HFC-134a (4.5 $MMTCO_2e$), and HFC-143a (3.5 $MMTCO_2e$).

U.S. HFC emissions in 2005 were 265 percent (95.7 $MMTCO_2e$) above the 1990 level of 36.1 $MMTCO_2e$. Since 1990, HFC emissions have accounted for a growing share of total emissions of HFCs, PFCs, and SF_6 combined (82 percent in 2005, compared with 41 percent in 1990). By far the largest portion of HFC emissions, 88 percent, can be attributed to their use as replacements for ODS. Emissions of HFCs used as substitutes for ODS (such as HFC-32, HFC-125, HFC-134a, HFC-143a, and HFC-236fa) have grown from trace amounts in 1990 to 112.6 $MMTCO_2e$ in 2005. ODS substitutes—used mainly in refrigeration and air conditioning (85 percent of total use), aerosols (11 percent), and solvents (2 percent)—were the largest and fastest growing sources of all HFC, PFC, and SF_6 emissions through 2004.[77]

HFCs are compounds containing carbon, hydrogen, and fluorine. Although they do not destroy stratospheric ozone, they are powerful greenhouse gases. HFCs are used in many applications, such as solvents, domestic and commercial refrigerants, firefighting agents, propellants for pharmaceutical and industrial aerosols, foam-blowing agents, and in blends for air conditioning refrigerants.

The market for HFCs is expanding. As CFCs and ODS are being phased out under the Montreal Protocol and the Clean Air Act, HFCs have been introduced into the market to fill the void in many key applications. For example, HFCs are used in fire protection applications to replace Halon 1301 and Halon 1211, which are no longer being produced in the United States.[78] HCFCs, now interim replacements for CFCs, will also be phased out. For example, HCFC-141b and HCFC-142b, which are used as blowing agents in insulation foams, will be replaced by HFCs for some uses.[79]

Trifluoromethane (HFC-23)

The EPA estimates 2005 emissions of HFC-23 at 17.3 $MMTCO_2e$.[80] HFC-23 emissions, representing 13 percent of total HFC emissions in 2005, were 5.8 percent (0.9 $MMTCO_2e$) above their 2004 level of 16.3 $MMTCO_2e$ but still 52 percent (18.8 $MMTCO_2e$) below their 1990 level of 36.1 $MMTCO_2e$. Since 1990, annual HFC-23 emissions have fluctuated, peaking in 1998 at 41.6 $MMTCO_2e$ and then falling steadily before edging up in 2004 and 2005.

Nearly all HFC-23 emissions (98 percent) are created as a byproduct in the production of chlorodifluoromethane (HCFC-22) and generally are vented to the atmosphere. In some cases the HFC-23 is captured for use in a limited number of applications. While production of HCFC-22 peaked in 2000, emissions of HFC-23 from this source declined from 1998 until 2003, because the HFC-23 emission rate (i.e., the amount of HFC-23 emitted per kilogram of HCFC-22 manufactured) decreased

[76] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006. Note that EIA calculates emissions in carbon dioxide equivalent units using the GWP values published by the IPCC in 2001 in its Third Assessment Report, whereas the EPA uses GWP values from the IPCC's 1996 Second Assessment Report.

[77] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[78] European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/en/applications/other_app/firefighting.html.

[79] European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/en/applications/insulation_foams.html.

[80] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.

Revisions in EPA Emissions Estimation Methodology

The primary source for the emissions estimates presented in this chapter is data obtained from the U.S. Environmental Protection Agency (EPA), Office of Air and Radiation. The Office of Air and Radiation also prepares an annual inventory of greenhouse gas emissions, which is published pursuant to U.S. commitments under the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC encourages parties to revise methods regularly and to recalculate emissions affected by the revisions. The data supporting the EPA inventory, including the emissions estimates for 2005, incorporate a number of revisions to the data and estimation methodologies used for hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) in its most recent emissions inventory.[a] Those changes are reflected in the EPA's historical emissions estimates, as described below:

- *Electricity Transmission and Distribution.* Changes in the calculations of emissions from electricity transmission and distribution resulted in an average annual increase in estimated SF_6 emissions from electric power systems of 0.1 to 0.6 million metric tons carbon dioxide equivalent ($MMTCO_2e$) for the 1990-2003 period.
- *Magnesium Production and Processing.* Emissions estimates from the EPA have been revised to reflect more accurate data on emission factors for sand casting activities and updated historical secondary production data from the U.S. Geological Survey (USGS). The changes resulted in a decrease in estimated SF_6 emissions from magnesium production and processing of 0.1 $MMTCO_2e$ (5 percent) for 2002.
- *Substitution of Ozone-Depleting Substances.* The EPA has updated assumptions for its Vintaging Model pertaining to trends in chemical substitutions, market size and growth rates, and amounts used. The changes resulted in an average annual net decrease in estimated HFC and PFC emissions of 2.0 $MMTCO_2e$ (3 percent) for the 1990-2003 period.
- *Aluminum Production.* The EPA has revised smelter-specific emissions factors and aluminum production levels to reflect recently reported data on smelter operating parameters. The changes resulted in an average annual increase of less than 0.5 $MMTCO_2e$ (0.4 percent) for the 1990-2003 period.

[a]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

significantly, and two of the three plants that manufacture HCFC-22 introduced the use of thermal oxidation.[81] Production of HCFC-22 also fell significantly between 2000 and 2005, to a level equal to 1995 production.[82]

HCFC-22 is used as a component of blowing agents for polyurethane foams and extruded polystyrene foams, and in the refrigerant market for stationary refrigeration and air conditioning (including chillers, room and household [central] air conditioners, and dehumidifiers). The EPA administers a voluntary program (the HFC-23 Emission Reduction Program) with HCFC-22 producers to reduce HFC-23 emissions, which has helped to moderate HFC-23 emissions during periods of rising demand for HCFC-22. In the long term, domestic production of HCFC-22 for non-feedstock uses will be phased out by 2020 under the U.S. Clean Air Act, pursuant to U.S. agreements under the Copenhagen Amendments to the Montreal Protocol. However, HCFC-22 production for use as a feedstock in the production of other chemicals (fluorinated polymers) will be allowed to continue indefinitely.[83]

Difluoromethane (HFC-32)

The EPA estimates 2005 emissions of HFC-32 at 0.4 $MMTCO_2e$.[84] HFC-32 emissions, representing 0.3 percent of total HFC emissions in 2005, were 23 percent (0.1 $MMTCO_2e$) above their 2004 level of 0.3 $MMTCO_2e$, and up by 459 percent (0.4 MMTCO2e) since first appearing in 1996. HFC-32 is increasingly being used to replace HCFC-22 in refrigerant blends.

[81]Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.
[82]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.
[83]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.
[84]Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.

The EPA Vintaging Model: Estimation Methods and Uncertainty

The U.S. Environmental Protection Agency (EPA) uses a detailed Vintaging Model for equipment and products containing ozone-depleting substances (ODS) and ODS substitutes to estimate actual versus potential emissions of various ODS substitutes, including hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). The model estimates the quantities of equipment and products sold each year that contain ODS and ODS substitutes, and the amounts of chemicals required for their manufacture and/or maintenance over time. Emissions from more than 50 different end uses are estimated by applying annual leak rates and release profiles, which account for the lag in emissions from equipment as it leaks over time.

For most products (refrigerators, air conditioners, fire extinguishers, etc.), emissions calculations are split into two categories: emissions during equipment lifetime, which arise from annual leakage and service losses plus emissions from manufacture; and disposal emissions, which occur when the equipment is discarded. By aggregating the data over different end uses, the model produces estimates of annual use and emissions of each compound.[a]

The EPA periodically attempts to improve the model and reduce the uncertainty of emissions estimates by using more accurate data from emitting industries. The level of detail incorporated in the EPA Vintaging Model is higher than that of the default methodology used by the Intergovernmental Panel on Climate Change, although there still is some uncertainty about some of the model inputs, such as equipment characteristics and sales figures, and end-use emissions profiles.

[a]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2003*, EPA-430-R-05-003 (Washington, DC, April 2005), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2005.html.

Pentafluoroethane (HFC-125)

The EPA estimates U.S. emissions of HFC-125 in 2005 at 22.1 $MMTCO_2e$, equivalent to 17 percent of total HFC emissions.[85] The 2005 emissions level is 12 percent (2.3 $MMTCO_2e$) higher than the 2004 level of 19.8 $MMTCO_2e$. Emissions of HFC-125 have increased steadily from 0.7 $MMTCO_2e$ in 1992 because of its use as a refrigerant blending agent.

HFC-125 is used in the blend R-410A, which is designed to replace HCFC-22 as the refrigerant of choice for stationary commercial refrigeration and air conditioning applications, as well as in the blends R-404A and R-507A. Some manufacturers have already introduced air conditioners that use R-410A, but as yet the product has captured only a small percentage of the market. As the phaseout of HCFC-22 begins to gain momentum, producers expect a rapid increase in demand for R-410A.[86] HFC-125 can also be used as a firefighting agent.

Tetrafluoroethane (HFC-134a)

The EPA estimates 2005 U.S emissions of HFC-134a at 66.1 $MMTCO_2e$.[87] HFC-134a accounts for the largest share of total HFC emissions (50 percent). The 2005 emissions level is 7.3 percent (4.5 $MMTCO_2e$) higher than the 2004 level of 61.6 $MMTCO_2e$. The increase can be attributed primarily to the continued use of HFC-134a as a substitute for CFCs in motor vehicle air conditioning systems.

Annual HFC-134a emissions have grown dramatically from their estimated 1992 level of 0.6 $MMTCO_2e$. Since 1994, HFC-134a has been the transportation industry standard for replacing CFCs in air conditioners for passenger cars, trucks, trains, and buses, because it is nonflammable, has low toxicity, and is not an ODS.

HFC-134a is also used in refrigerant blends (e.g., R-404A) in most new commercial refrigeration equipment built in the United States and in commercial chillers, but leakage from these sources is much less than from automotive air conditioners. Leakage occurs primarily during the servicing of the units rather than during normal operation. Short-term uses of HFC-134a, on the other hand, are becoming an important source of emissions. Such uses include aerosol propellants and open-cell foam blowing, which are denoted as short-term uses because most of the HFC-134a used will be emitted to the atmosphere within a short period of time. In 1994, HFC-134a began to be used as solvents and sterilants. According to the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), worldwide sales of HFC-134a jumped more than fourfold

[85]Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.
[86]J. Ouellette, "Fluorocarbon Market Is Poised To Grow," *Chemical Market Reporter* (June 19, 2000).
[87]Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.

between 1992 and 1993, doubled again in 1994, and continued growing steadily to 166,899 metric tons of gas in 2003.[88]

Trifluoroethane (HFC-143a)

The EPA estimates U.S. emissions of HFC-143a in 2005 at 23.0 $MMTCO_2e$, equivalent to 17 percent of total HFC emissions.[89] The 2005 emissions level is 18 percent (3.5 $MMTCO_2e$) higher than the 2004 level of 19.5 $MMTCO_2e$. HFC-143a emissions have increased rapidly from 0.1 $MMTCO_2e$ in 1993, as demand for HFC-143a as a refrigerant blending agent has increased.

HFC-143a is a halocarbon used in blends for commercial refrigeration and air conditioning, such as R-404A and R-507A. HFC-143a, like other HFCs, is used as a substitute because it contains neither chlorine nor bromine and does not emit ozone-depleting halogen radicals into the stratosphere. Like other halocarbons, HFC-143a does make a positive contribution to atmospheric warming; however, the GWPs of R-404A and R-507A are lower than those of the gases it replaces, such as CFC-12 with a GWP of 10,600.

Hexafluoropropane (HFC-236fa)

The EPA estimates U.S. emissions of HFC-236fa in 2005 at 2.9 $MMTCO_2e$, equivalent to 2.2 percent of total HFC emissions.[90] The 2005 emissions level is 17 percent (0.6 $MMTCO_2e$) lower than the 2004 level of 3.5 $MMTCO_2e$. Emissions of HFC-236fa have increased from 0.1 $MMTCO_2e$ in 1997 because of its use as a refrigerant, in particular by the U.S. Navy for shipboard applications.[91] In another application, HFC-236fa is used as a fire-fighting agent.

Perfluorocarbons (PFCs)

The EPA estimates 2005 emissions of PFCs at 6.7 $MMTCO_2e$, accounting for 4.2 percent of all emissions of HFCs, PFCs, and SF_6 combined. The estimate for 2005 is 5.2 percent (0.4 $MMTCO_2e$) lower than the estimate for 2004 (7.0 $MMTCO_2e$) and 67 percent (13.3 $MMTCO_2e$) lower than the 1990 emissions level of 20.0 $MMTCO_2e$.[92] The downward trend in emissions is largely the result of decreases in domestic aluminum production, which creates PFCs as byproducts, as well as process efficiency improvements in the aluminum industry. Moderating the decrease in emissions of the PFCs perfluoromethane (CF_4) and perfluoroethane (C_2F_6) from aluminum manufacture have been increases in their emissions from semiconductor manufacture, which also produces emissions of perfluoropropane (C_3F_8), perfluorobutene (C_4F_8), and nitrogen trifluoride (NF_3).

Perfluoromethane (CF_4)

The EPA estimates U.S. emissions of CF_4 in 2005 at 3.2 $MMTCO_2e$, equivalent to 48 percent of total PFC emissions.[93] The 2005 emissions level is 0.5 percent (less than 0.1 $MMTCO_2e$) lower than the 2004 level of 3.2 $MMTCO_2e$. CF_4 emissions have dropped by a total of 78 percent (11.4 $MMTCO_2e$) from their 1990 level of 14.6 $MMTCO_2e$.

The two principal sources of CF_4, as well as C_2F_6, are as a byproduct of aluminum smelting created during periods of process inefficiency and disruption, and in the manufacture of semiconductors. The EPA estimates U.S. CF_4 emissions in 2005 from aluminum production at 2.2 $MMTCO_2e$ and from semiconductor manufacture at 0.9 $MMTCO_2e$.[94] With reductions in primary aluminum production and improvements that reduce anode effects leading to process inefficiency, CF_4 emissions from aluminum smelting have been reduced by 84 percent (11.7 $MMTCO_2e$) from their 1990 level of 13.9 $MMTCO_2e$.

U.S. Emissions of Perfluorocarbons, 1990-2005

Estimated 2005 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	6.7
Change Compared to 2004 (Million Metric Tons Carbon Dioxide Equivalent)	-0.4
Change from 2004 *(Percent)*	*-5.2%*
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	-13.3
Change from 1990 *(Percent)*	*-66.6%*

[88] Alternative Fluorocarbons Environmental Acceptability Study, Production, Sales and Atmospheric Release, web site www.afeas.org/2003/html/hfc-134a.html.
[89] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.
[90] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.
[91] E-mail correspondence with the Office of Policy, U.S. Department of Energy, October 18, 2000.
[92] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006. Note that EIA calculates emissions in carbon dioxide equivalent units using the GWP values published by the IPCC in 2001 in its Third Assessment Report, whereas the EPA uses GWP values from the IPCC's 1996 Second Assessment Report.
[93] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.
[94] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.

Aluminum smelting companies that participate in the EPA's Voluntary Aluminum Industry Partnership (VAIP) have achieved efficiency improvements through voluntary actions. Reductions in primary aluminum production have also played a role in reducing PFC emissions. According to data from the U.S. Geological Survey (USGS), domestic primary aluminum production fell between 2003 and 2004 and held steady in 2005. The decline in production resulted from cutbacks in smelter production in response to higher costs of energy and alumina. Most of the production cutbacks took place in the Pacific Northwest.[95]

Another source of CF_4 emissions is semiconductor manufacturing. Emissions from this source peaked in 2000 at just over 1.6 $MMTCO_2e$ and have since declined by 42 percent (0.1 $MMTCO_2e$) to their 2005 level of 0.9 $MMTCO_2e$.[96] This estimate reflects the rapid growth of the semiconductor industry in the 1990s, which has resulted in a 42-percent increase in emissions (0.3 $MMTCO_2e$) from their 1990 level of 0.7 $MMTCO_2e$. CF_4, like C_2F_6, is used as a plasma etchant and cleaning agent in semiconductor manufacturing; some of the gas used in those processes does not react with the materials and, unless abated, is emitted to the atmosphere.

Perfluoroethane (C_2F_6)

The EPA estimates U.S. emissions of C_2F_6 in 2005 at 3.0 $MMTCO_2e$, equivalent to 46 percent of total PFC emissions.[97] The 2005 emissions level is 11.5 percent (0.4 $MMTCO_2e$) below the 2004 level of 3.4 $MMTCO_2e$. Emissions of C_2F_6 have dropped by 43 percent (2.3 $MMTCO_2e$) from their 1990 level of 5.4 $MMTCO_2e$.

C_2F_6 emissions originate from the aluminum and semiconductor industries. Thus, C_2F_6, like CF_4, has had two countervailing trends bearing on its emissions levels. On one side, decreasing aluminum production and increased efficiency in the aluminum industry have tended to lower emissions. C_2F_6 emissions in the aluminum industry fell from 3.5 $MMTCO_2e$ in 1990 to 0.5 $MMTCO_2e$ in 2005, or by 85 percent (2.9 $MMTCO_2e$). On the other side, increased semiconductor production has tended to increase emissions. C_2F_6 emissions in the semiconductor industry, estimated by the EPA at 2.5 $MMTCO_2e$ in 2005, have increased by 32 percent (0.6 $MMTCO_2e$) from their 1990 level of 1.9 $MMTCO_2e$. The net effect has been a 43-percent overall reduction in emissions of C_2F_6 since 1990.

Other HFCs and PFCs/PFPEs

There is a group of other HFCs and PFCs/PFPEs for which the EPA withholds individual emissions data, because the data are considered confidential and could compromise business practices. This group includes HFC-152a, HFC-227ea, HFC-245fa, and HFC-4310mee.[98] The EPA estimates total emissions of this group of "other HFCs" at 6.1 $MMTCO_2e$ in 2005, representing 3.8 percent of all emissions of HFCs, PFCs, and SF_6 reported.[99] Emissions of these HFCs are small but growing rapidly, as they continue to find applications as substitutes for CFCs and HCFCs. Emissions of "other HFCs" increased by 13 percent (0.7 $MMTCO_2e$) in 2005 compared with 2004 (5.4 $MMTCO_2e$).

Other HFCs and HFC blends are also likely to gain market share as a result of the phaseout of CFCs and HCFCs, because no single product is suited for all applications. For example, each potential replacement product has an optimal operating temperature range; hence, the refrigerant best suited for use in ice cream freezers will differ from the best choice for milk coolers.[100]

In addition to replacing HCFC-22 in stationary air conditioning and refrigeration applications, other HFCs are expected to gain new markets as foam-blowing agents. CFCs have already been phased out of this market, having been replaced by HCFCs (primarily HCFC-141b). Among the potential replacements for HCFCs, HFC-245fa (pentafluoropropane) appears to be the strongest contender.[101]

Sulfur Hexafluoride (SF_6)

The EPA estimates 2005 emissions of SF_6 at 15.7 $MMTCO_2e$, accounting for 9.8 percent of all HFC, PFC, and SF_6 emissions combined in 2005.[102] Emissions in 2005 were 2.1 percent (0.3 $MMTCO_2e$) lower than in 2004

[95] U.S. Department of the Interior, U.S. Geological Survey, *Mineral Commodity Summaries 2006*, web site http://minerals.usgs.gov/minerals/pubs/mcs/2006/mcs2006.pdf.

[96] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.

[97] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.

[98] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 388.

[99] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006. Note that EIA calculates emissions in carbon dioxide equivalent units using the GWP values published by the IPCC in 2001 in its Third Assessment Report, whereas the EPA uses GWP values from the IPCC's 1996 Second Assessment Report.

[100] C. Boswell, "Hydrofluorocarbons Build with Transition Away from CFCs," *Chemical Market Reporter* (September 13, 1999).

[101] C. Boswell, "Hydrofluorocarbons Build with Transition Away from CFCs," *Chemical Market Reporter* (September 13, 1999).

[102] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006. In compiling its estimates, the EPA receives data from participants in the SF_6 Emission Reduction Partnership for Electric Power Systems and the SF_6 Emission Reduction Partnership for the Magnesium Industry.

U.S. Emissions of Sulfur Hexafluoride, 1990-2005

Estimated 2005 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	15.7
Change Compared to 2004 (Million Metric Tons Carbon Dioxide Equivalent)	-0.3
Change from 2004 *(Percent)*	*-2.1%*
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	-15.0
Change from 1990 *(Percent)*	*-48.9%*

(16.0 $MMTCO_2e$) and 49 percent (15.0 $MMTCO_2e$) lower than the estimate for 1990 (30.7 $MMTCO_2e$). The downward trend in SF_6 emissions since 1990 is the result of industry efforts to reduce emissions from electrical power systems, as well as the rising cost of SF_6. In contrast, emissions of SF_6 from uses in the semiconductor manufacturing industry have increased overall by 84 percent since 1990.

SF_6 is used primarily in electrical applications, in which it is an excellent dielectric gas for high-voltage applications, because it is chemically inert, gaseous at low temperatures, nonflammable, nontoxic, and noncorrosive.[103] In electricity transmission and distribution systems, SF_6 acts as an insulator and arc interrupter for circuit breakers, switch gear, and other electrical equipment; however, it can escape through seals, especially in older equipment. Emissions also occur during equipment installation, servicing, and disposal.[104]

Other applications that produce SF_6 emissions include magnesium metal casting processes that employ SF_6 to replace toxic and corrosive materials, such as salt fluxes and sulfur dioxide (SO_2). Another use of SF_6 is as a cover gas during magnesium production and processing to prevent excessive oxidation of molten magnesium in the presence of air. Although emissions from this source have declined, due in part to process optimizations by industry participants in EPA's SF_6 Emission Reduction Partnership for the Magnesium Industry, there was a 3-percent increase in the amount of metal processed in 2004.[105] Pre-treating aluminum melt with SF_6 (or an inert gas mixture) prevents porosity and therefore weakening of the metal. It also removes oxides and solid impurities. In addition, mixtures of SF_6 and O_2 are used as feed gases for plasma etching of semiconductor devices.[106] Because of its extremely low atmospheric concentration, SF_6 is also useful as an atmospheric tracer gas for a variety of experimental purposes. Other minor applications include leak detection, loudspeakers, lasers, and as a cover gas or fluxing and degassing agent for specialized casting operations in the aluminum industry.[107]

[103] European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/en/families/sf6/main_app.html.

[104] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[105] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-32 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[106] European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/en/families/sf6/main_app.html#c.

[107] Historically, emissions of SF_6 from the aluminum industry have been omitted from global estimates, because any emissions are expected to be insignificant. The EPA does not estimate emissions from this source due to uncertainties about the quantities used and the amounts destroyed in the applications.

Table 31. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990, 1995, and 1998-2005
(Million Metric Tons Carbon Dioxide Equivalent)

Gas	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Hydrofluorocarbons										
HFC-23	36.1	28.1	41.6	31.7	30.9	20.6	20.6	12.9	16.3	17.3
HFC-32	0.0	0.0	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4
HFC-125	0.0	4.4	10.7	12.1	13.6	14.9	16.3	17.9	19.8	22.1
HFC-134a	0.0	17.7	35.2	40.2	45.4	49.7	53.5	56.8	61.6	66.1
HFC-143a	0.0	0.9	5.9	7.5	9.3	11.4	13.8	16.5	19.5	23.0
HFC-236fa	0.0	0.0	0.6	1.3	2.0	2.6	3.2	3.5	3.5	2.9
Total HFCs	**36.1**	**51.0**	**94.2**	**93.1**	**101.5**	**99.4**	**107.6**	**107.8**	**121.1**	**131.8**
Perfluorocarbons										
CF_4	14.6	10.0	8.4	8.3	8.4	3.8	5.0	3.8	3.2	3.2
C_2F_6	5.4	5.4	5.8	5.8	4.9	3.3	3.8	3.3	3.4	3.0
NF_3	*	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3
C_3F_8	*	*	*	*	0.1	0.1	0.1	0.1	*	*
C_4F_8	*	*	*	*	*	*	0.1	0.1	0.1	0.1
Total PFCs	**20.0**	**15.5**	**14.2**	**14.2**	**13.6**	**7.3**	**9.2**	**7.6**	**7.0**	**6.7**
Other HFCs, PFCs/PFPEs	**0.4**	**2.1**	**4.9**	**5.0**	**4.9**	**4.7**	**4.7**	**4.7**	**5.4**	**6.1**
Sulfur Hexafluoride	**30.7**	**26.3**	**21.0**	**21.6**	**18.1**	**17.1**	**16.3**	**16.4**	**16.0**	**15.7**
Total Emissions	**87.1**	**94.9**	**134.3**	**133.9**	**138.0**	**128.5**	**137.8**	**136.6**	**149.5**	**160.2**

*Less than 50,000 metric tons carbon dioxide equivalent.
P = preliminary data.
Notes: Other HFCs, PFCs/PFPEs include HFC-152a, HFC-227ea, HFC-245fa, HFC-4310mee, and a variety of PFCs and perfluoropolyethers (PFPEs). They are grouped together to protect confidential data. Totals may not equal sum of components due to independent rounding.
Source: U.S. Environmental Protection Agency, Office of Air and Radiation, web site www.epa.gov/globalwarming/ (preliminary estimates, September and October 2006).

Table 32. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990, 1995, and 1998-2005
(Thousand Metric Tons of Gas)

Gas	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Hydrofluorocarbons										
HFC-23	3.0	2.3	3.5	2.6	2.6	1.7	1.7	1.1	1.4	1.4
HFC-32	0.0	0.0	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.8
HFC-125	0.0	1.3	3.1	3.6	4.0	4.4	4.8	5.3	5.8	6.5
HFC-134a	0.0	13.6	27.1	30.9	34.9	38.2	41.2	43.7	47.4	50.8
HFC-143a	0.0	0.2	1.4	1.7	2.2	2.6	3.2	3.8	4.5	5.4
HFC-236fa	0.0	0.0	0.1	0.1	0.2	0.3	0.3	0.4	0.4	0.3
Perfluorocarbons										
CF_4	2.6	1.8	1.5	1.5	1.5	0.7	0.9	0.7	0.6	0.6
C_2F_6	0.5	0.5	0.5	0.5	0.4	0.3	0.3	0.3	0.3	0.3
NF_3	*	*	*	*	*	*	*	*	*	*
C_3F_8	*	*	*	*	*	*	*	*	*	*
C_4F_8	*	*	*	*	*	*	*	*	*	*
Other HFCs, PFCs/PFPEs	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Sulfur Hexafluoride	**1.4**	**1.2**	**0.9**	**1.0**	**0.8**	**0.8**	**0.7**	**0.7**	**0.7**	**0.7**

*Less than 50 metric tons of gas.
P = preliminary data. M = mixture of gases.
Notes: Other HFCs, PFCs/PFPEs include HFC-152a, HFC-227ea, HFC-245fa, HFC-4310mee, and a variety of PFCs and perfluoropolyethers (PFPEs). They are grouped together to protect confidential data. Totals may not equal sum of components due to independent rounding.
Source: U.S. Environmental Protection Agency, Office of Air and Radiation, web site www.epa.gov/globalwarming/ (preliminary estimates, September and October 2006).